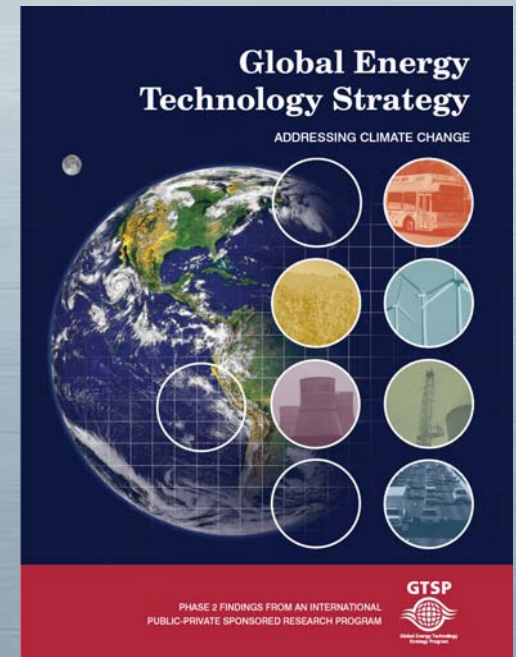




Stabilization and Technology in the Near-, Mid-, and Long-Term



Lessons from the Global Energy Technology Strategy Program Phase 2

Hugh Pitcher
September 13, 2007

PNNL-SA-51961



A Note on Units CO₂ Versus C

- 1 ton C = $44/12$ tons of CO₂
= $3\frac{2}{3}$ tons of CO₂
= ~4 tons of CO₂
- \$1/ton CO₂ = $\$3\frac{2}{3}$ tons of C
= ~\$4 tons of C

Both appear in the literature.

This presentation used tons of **carbon**.

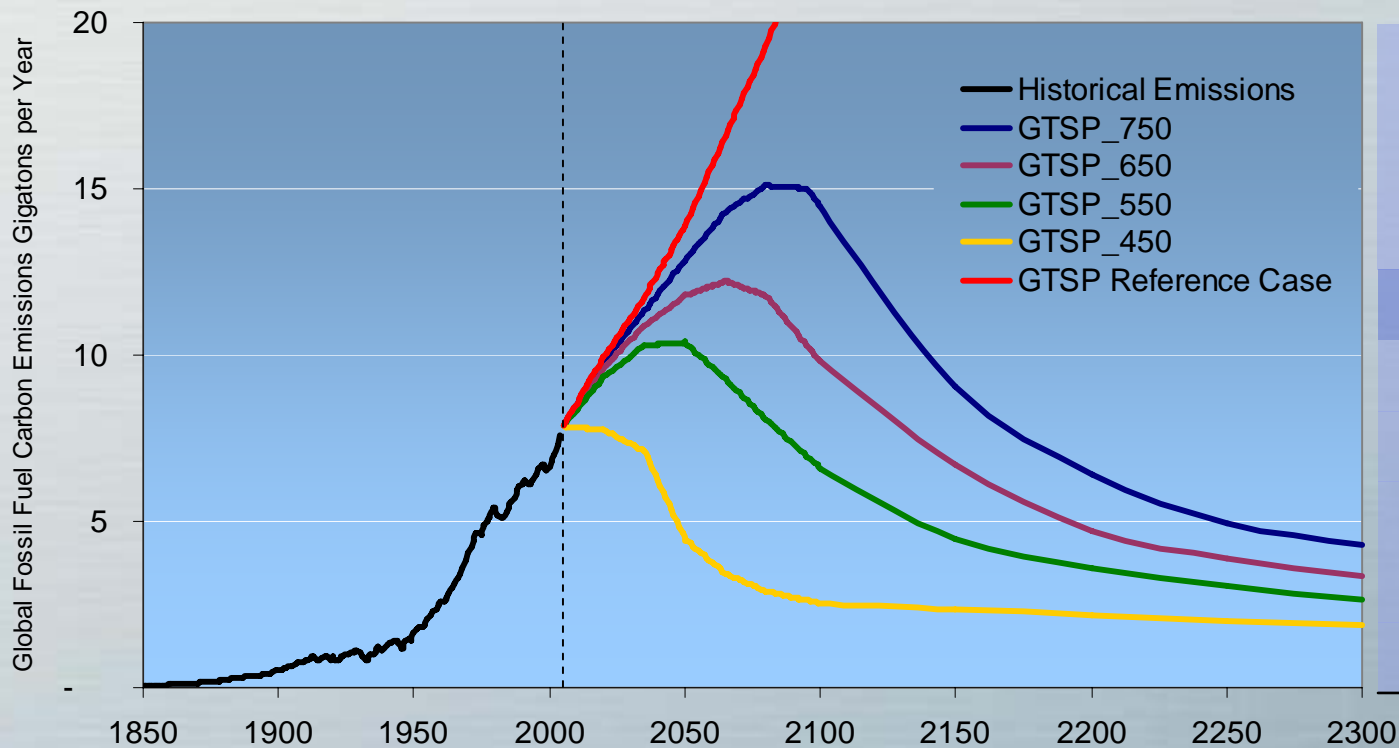
Key Findings of the GTSP

- Climate is a long-term problem, with implications for actions today.
- Stabilizing the concentration of CO₂ means fundamental change to the global energy system.
- Technology will play a central role in addressing a growing mitigation challenge in the near-, mid- and long-term.
- Six technology systems could play dramatically greater roles in a climate constrained world.

CO₂ capture and storage, Biotechnology, Hydrogen systems, Nuclear energy, Wind and solar, and End-use energy technologies, though none is a “silver bullet.”

- A strategy to develop and deploy technology should be part of a larger program—including scientific research, emissions limitation, and adaptation to climate change.

Climate change is a long-term strategic problem with implications for today



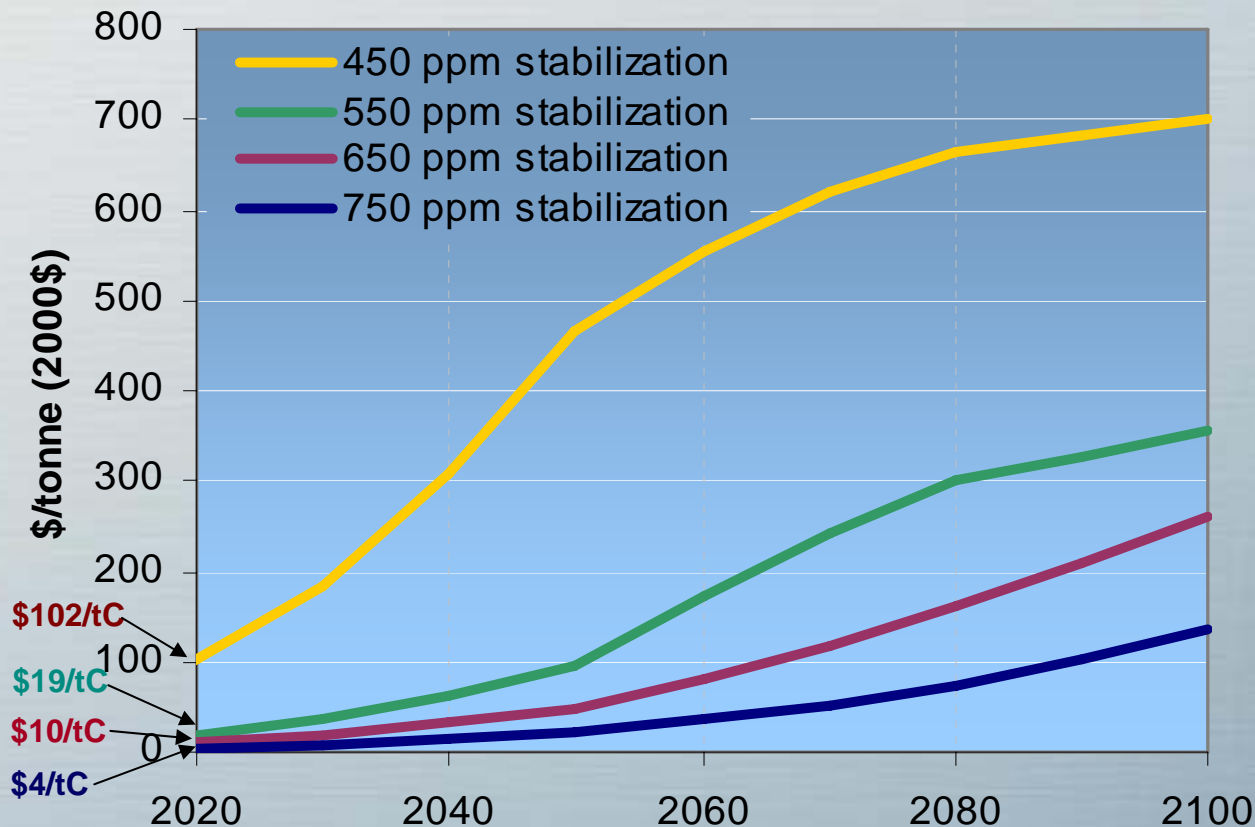
Fossil Fuel Carbon Emissions Historic & 2005 to 2100

1750-2005	300 GtC
GTSP Ref	1430 GtC
750 ppm	1200 GtC
650 ppm	1040 GtC
550 ppm	862 GtC
450 ppm	480 GtC

- Stabilization of greenhouse gas **concentrations** is the goal of the Framework Convention on Climate Change.
- Stabilizing CO₂ **concentrations** at any level means that **global**, CO₂ emissions must peak and then decline forever.

A global commitment to stabilizing CO₂ concentrations requires a carbon price that escalates over time

Global Value of Carbon



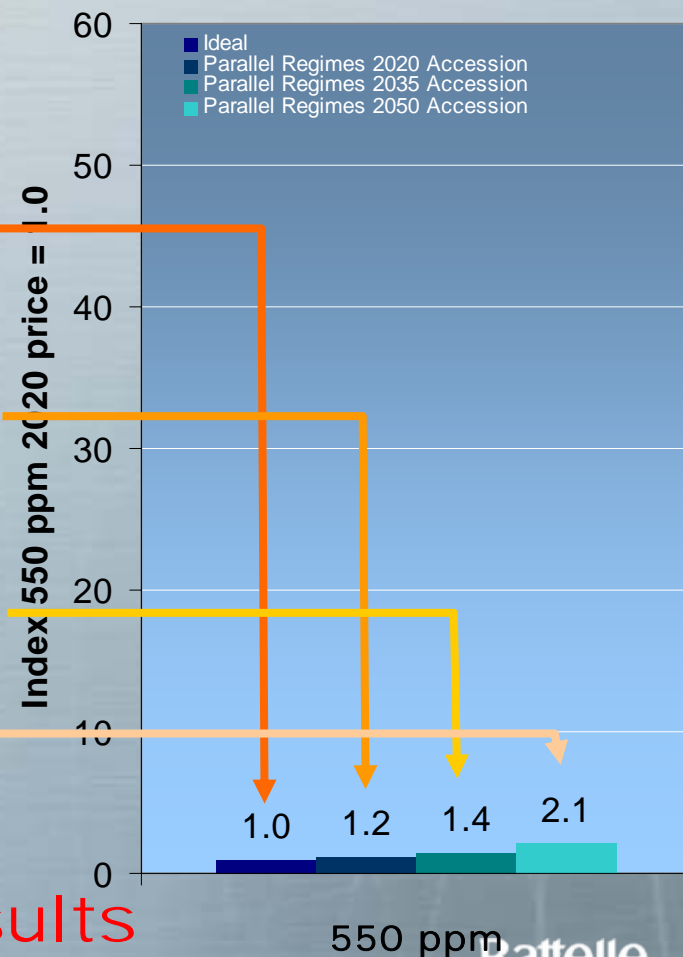
- Price of carbon should start low and rise steadily to minimize society's costs.
- Eventually all nations and economic sectors need to be covered as the atmosphere is indifferent as to the source of CO₂ emissions.
- The response to this escalating price of carbon will vary across economic sectors and regions.

Year 2020 Annex I carbon prices for different accession assumptions: 550 ppm

Near-term carbon prices depend on both the concentration at which CO₂ is stabilized and the degree and timing of Non-Annex I accession.

Four alternative assumptions:

1. The whole world starts emissions mitigations **immediately** with perfect “where” and “when” flexibility.
2. Annex I starts emissions mitigation immediately, but most non-Annex I starts in **2020** in a parallel regime.
3. Annex I starts emissions mitigation immediately, but most non-Annex I starts in **2035** in a parallel regime.
4. Annex I starts emissions mitigation immediately, but most non-Annex I start in **2050** in a parallel regime.



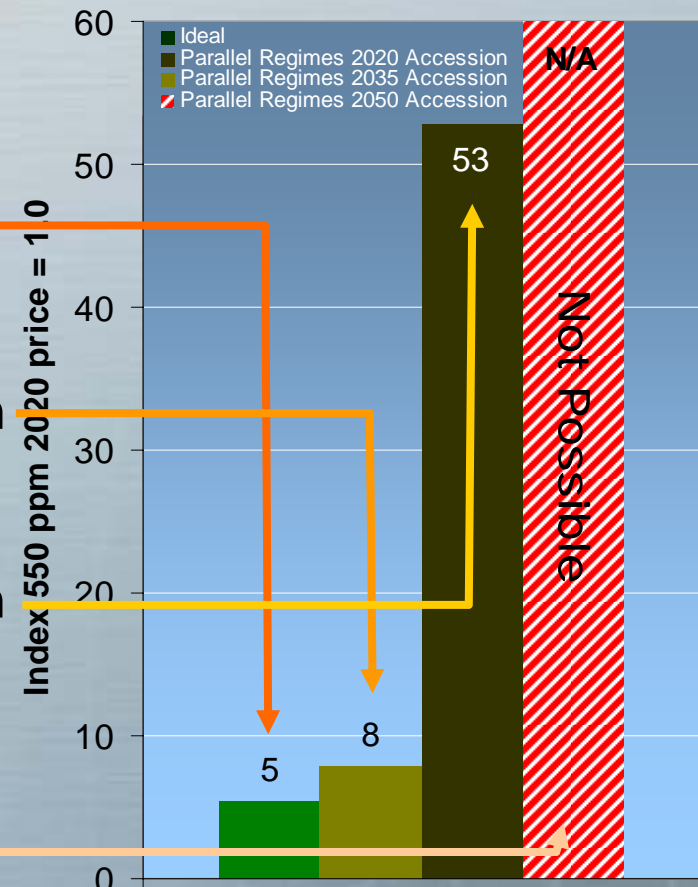
Preliminary Results
GTSP Phase 3

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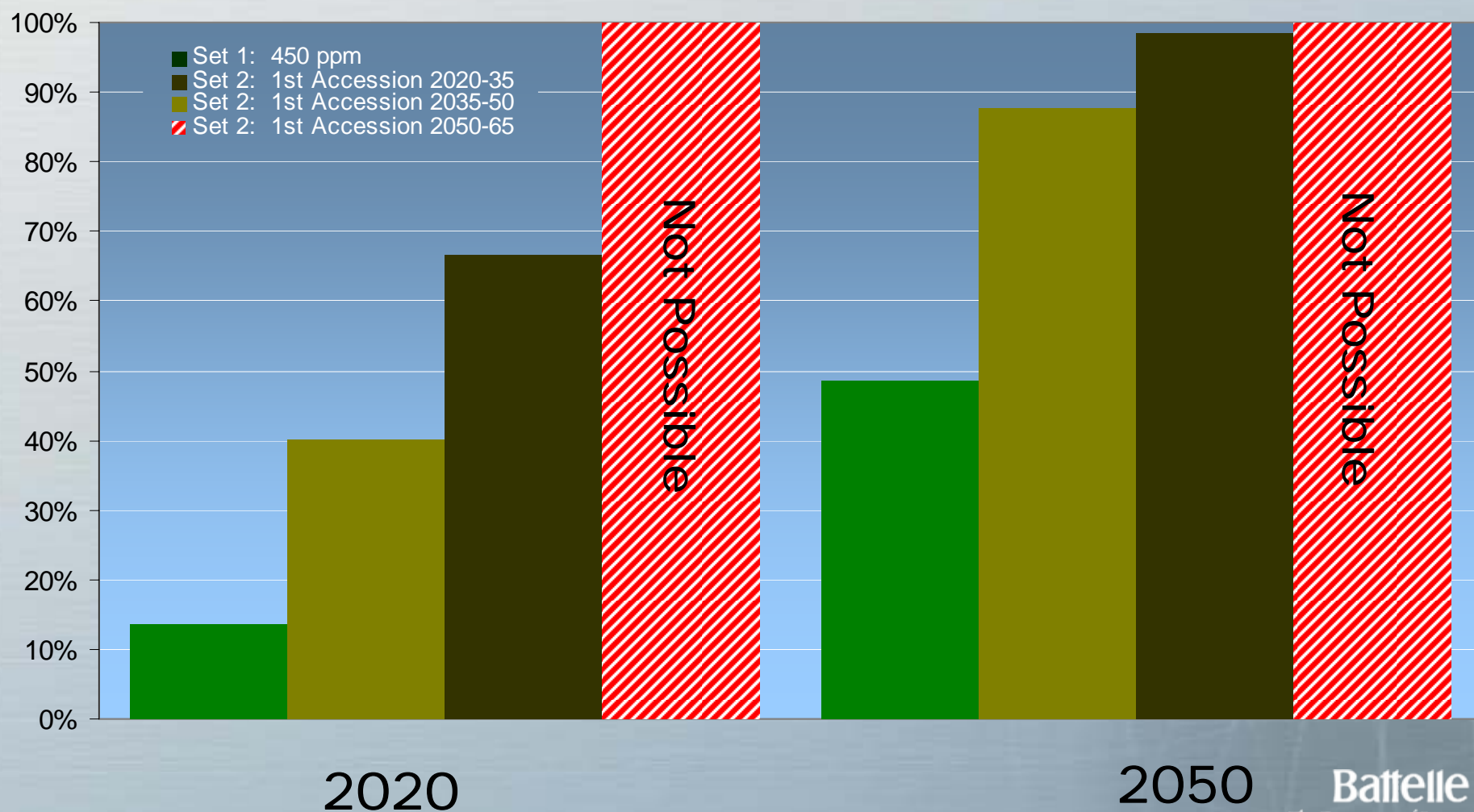
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Preliminary Results
GTSP Phase 3

Year 2020 Annex I emissions mitigation, relative to 2005, for different accession assumptions: 450 ppm

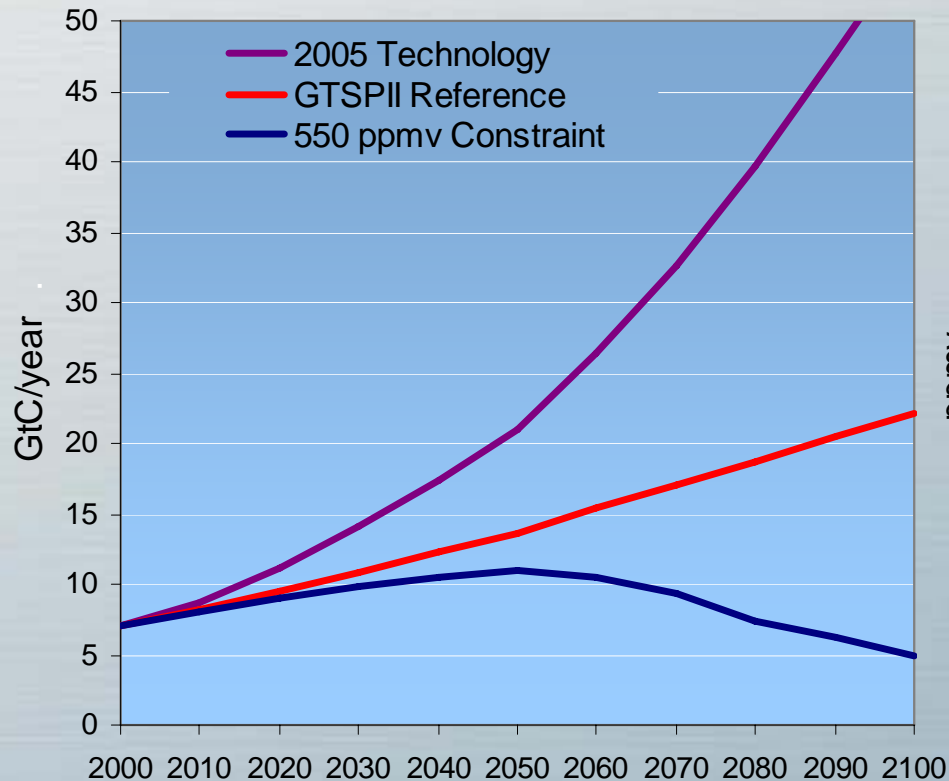
450 ppm



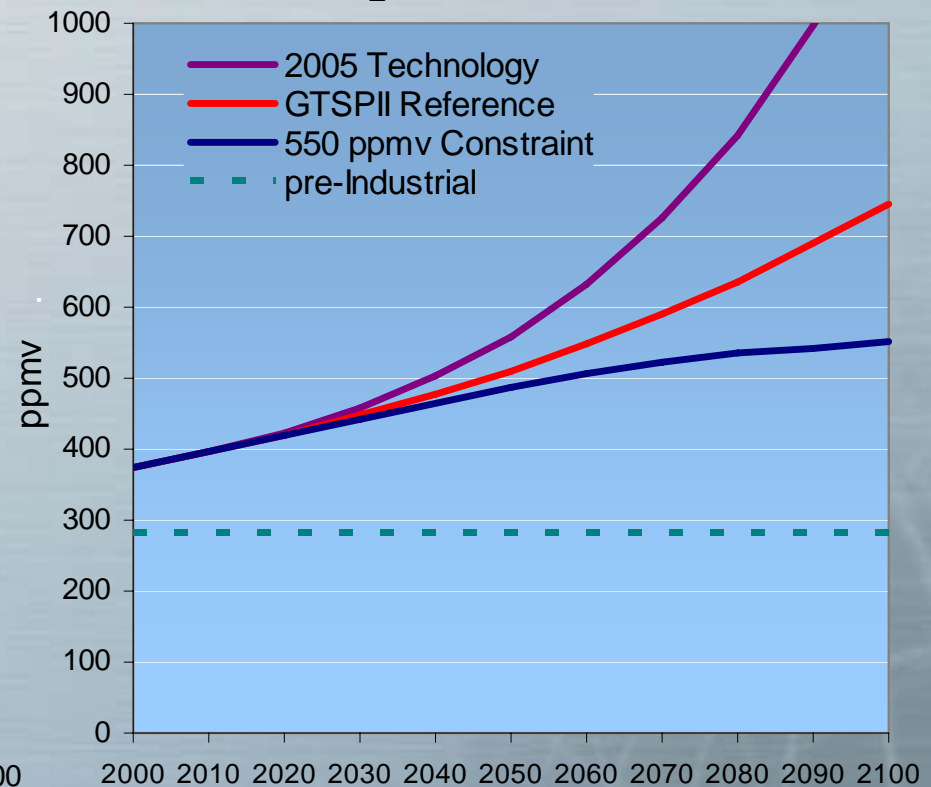
The role of technology

Future projections of energy use and CO₂ emissions assume significant technological progress in their no-climate-policy, business-as-usual cases

Carbon Emissions

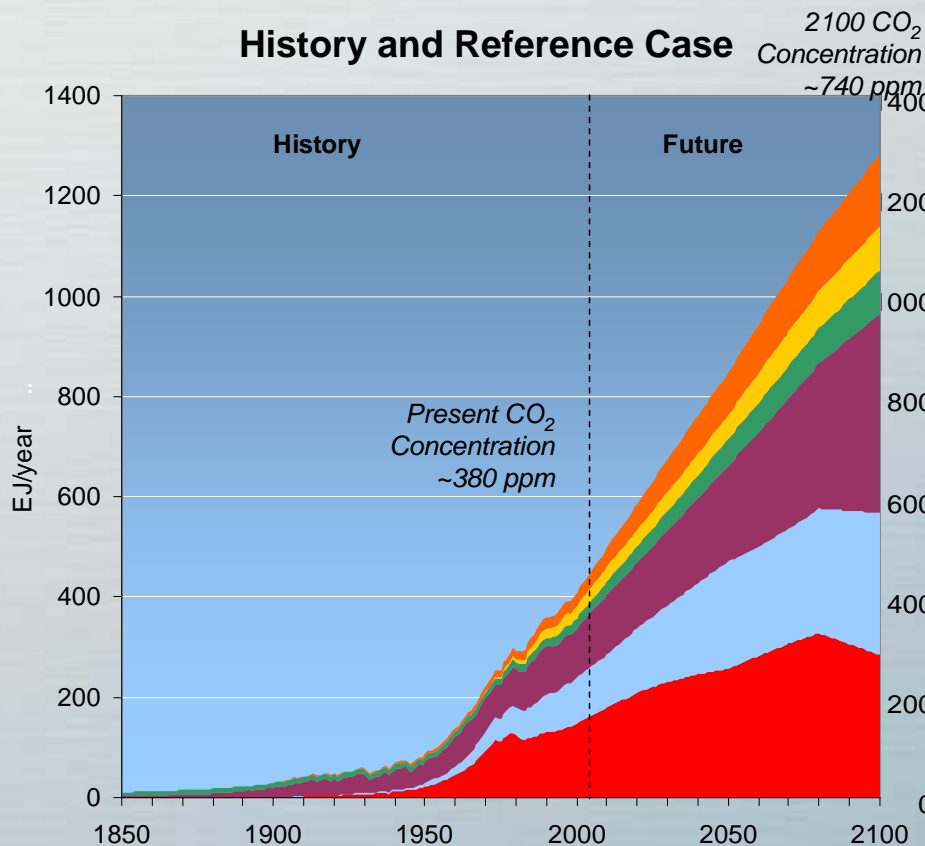


CO₂ Concentration

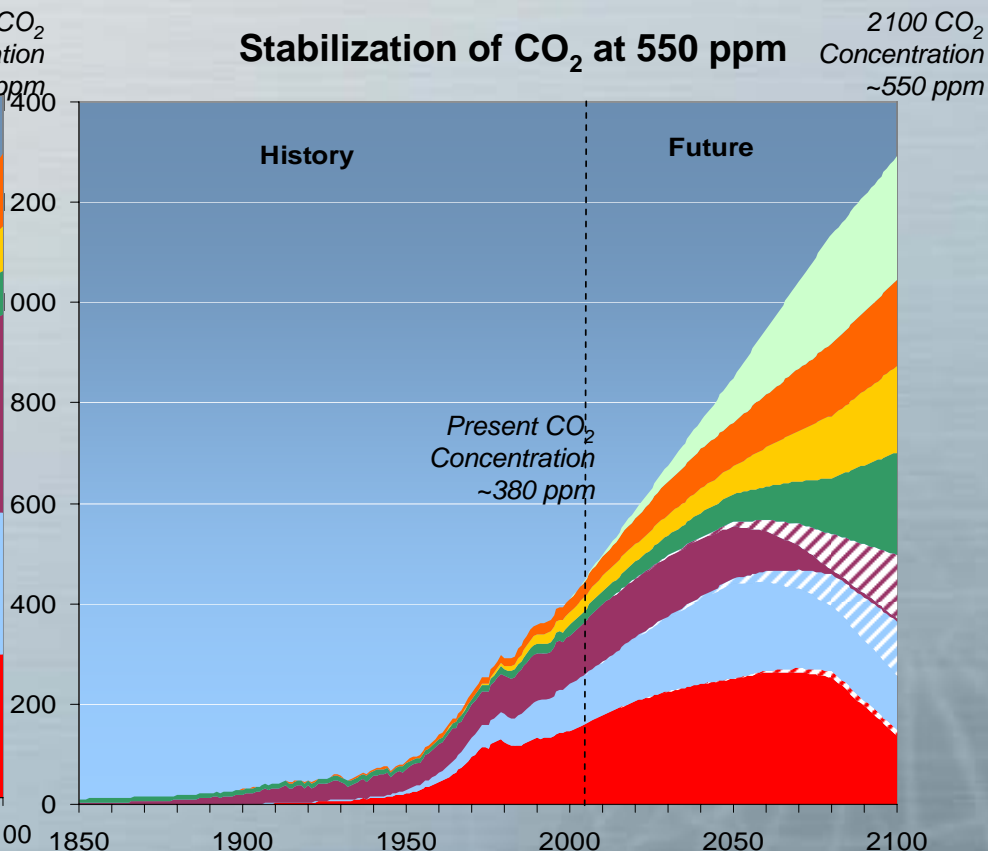


Stabilizing CO₂ concentrations means fundamental change to the global energy system

History and Reference Case



Stabilization of CO₂ at 550 ppm



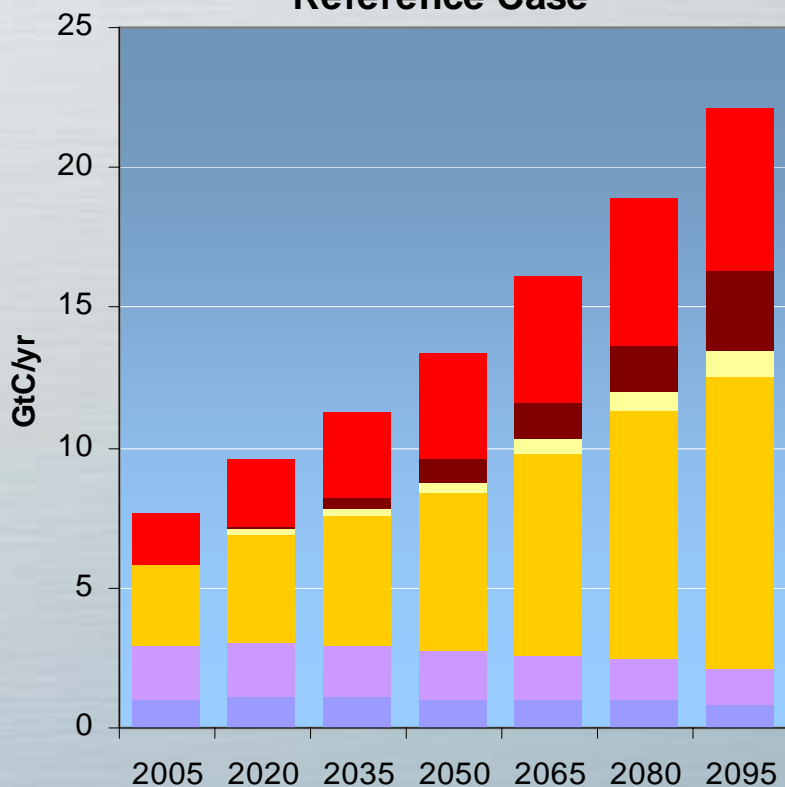
Oil
Natural Gas
Coal
Biomass Energy
Non-Biomass Renewable Energy

Oil + CCS
Natural Gas + CCS
Coal + CCS
Nuclear Energy
End-use Energy

The response to this escalating price of carbon will vary across economic sectors and regions.

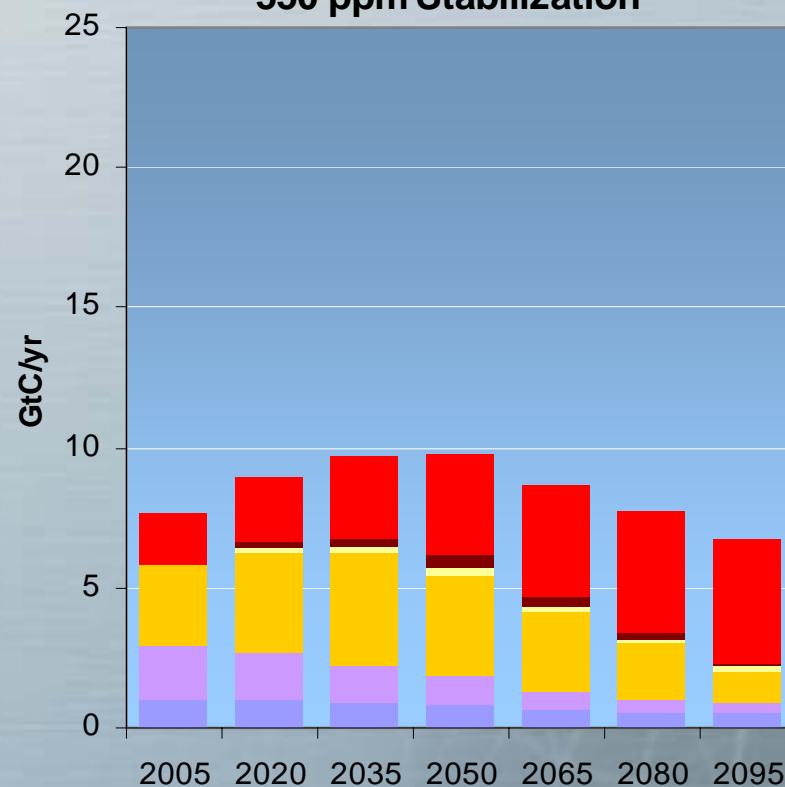
Stabilization changes the sources of fossil CO₂ emissions. Utility emissions drop to virtually zero. Transportation emissions dominate.

**Global Fossil Fuel CO₂ Emissions
Reference Case**



Buildings
Electricity
Natural Gas
Transportation
Industry
Hydrogen
Liquids Production

**Global Fossil Fuel CO₂ Emissions
550 ppm Stabilization**

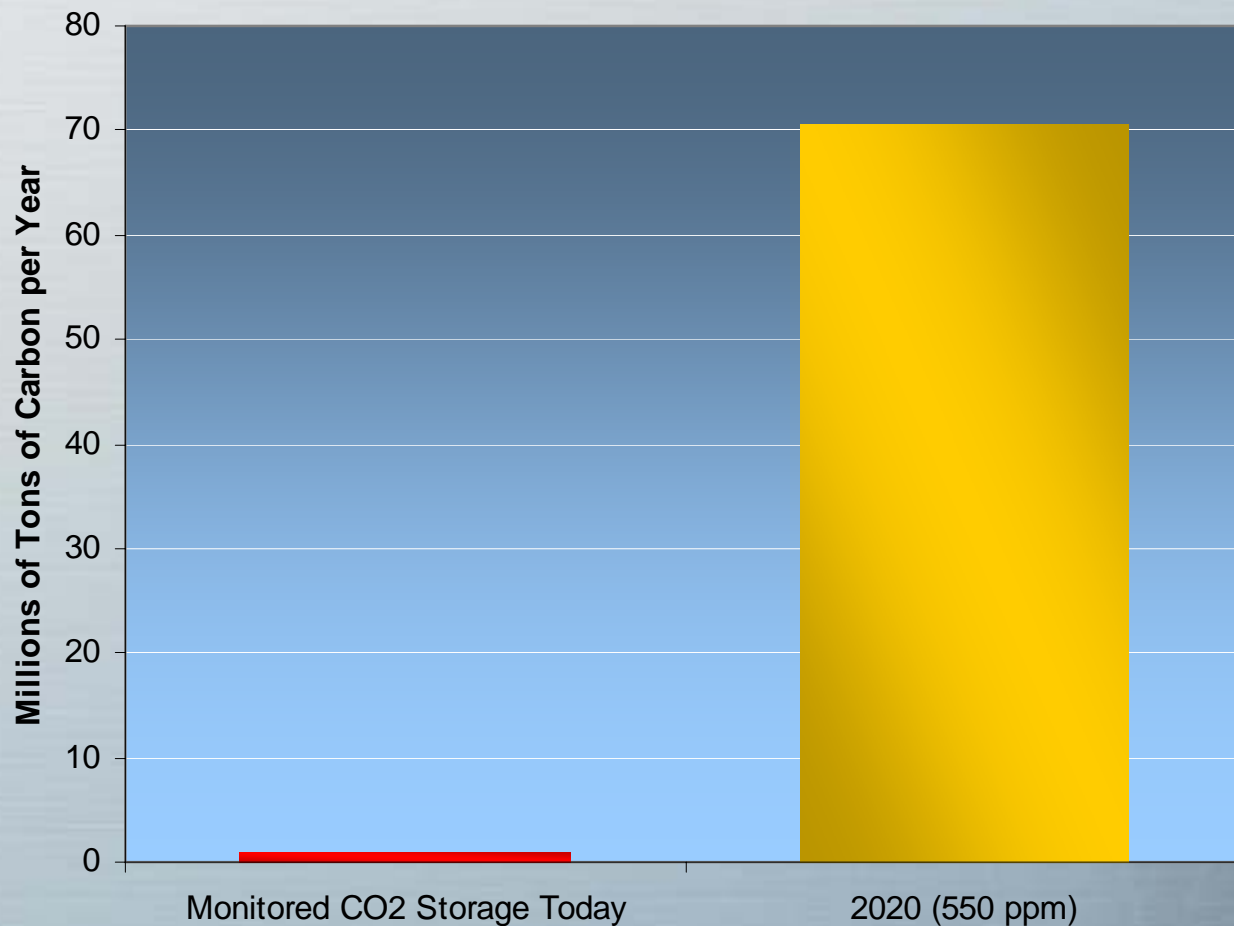


Buildings
Electricity
Natural Gas
Transportation
Industry
Hydrogen
Liquids Production

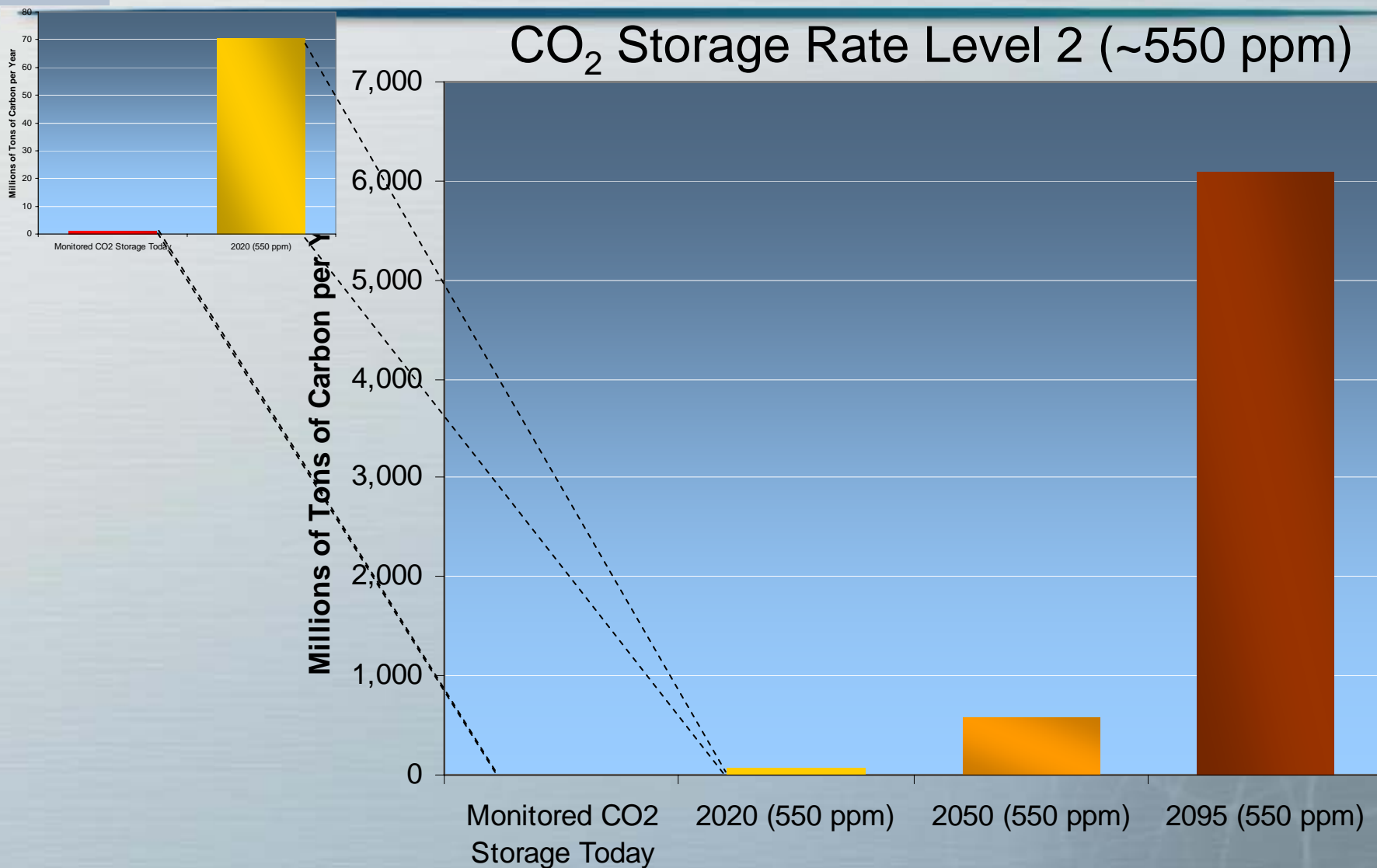
The challenge of scale

The Challenge of Scale— near term

CO₂ Storage—550 ppm Stabilization Case

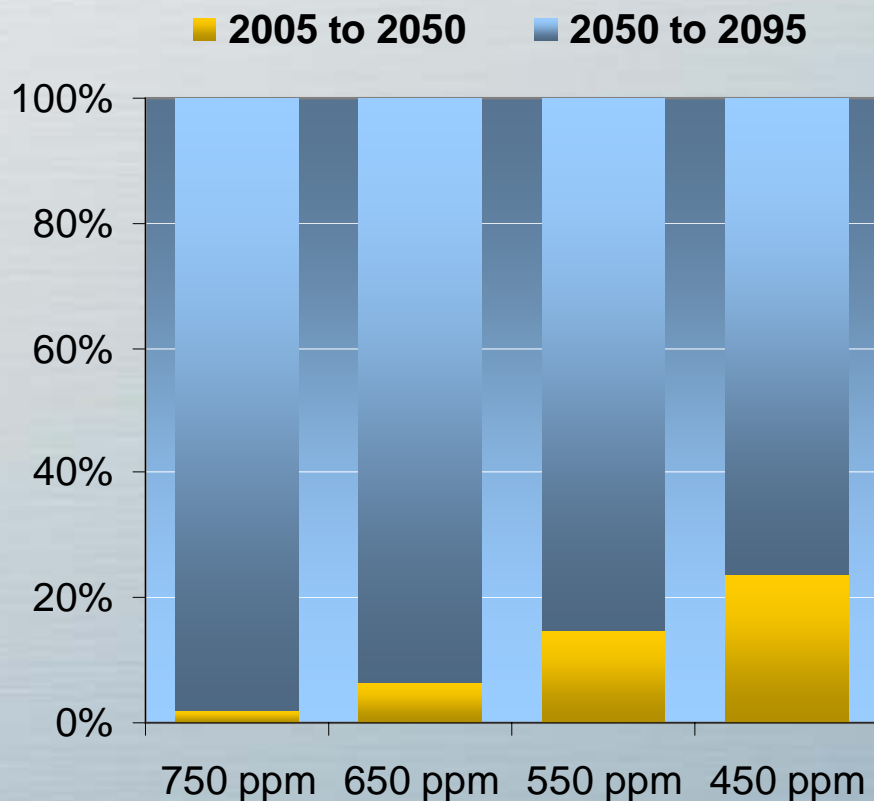


In the mid- and long-term the challenge grows



CO₂ emissions mitigation during 2005 to 2050 is just the start

Emissions Mitigation 2005 to 2050 and 2050 to 2095

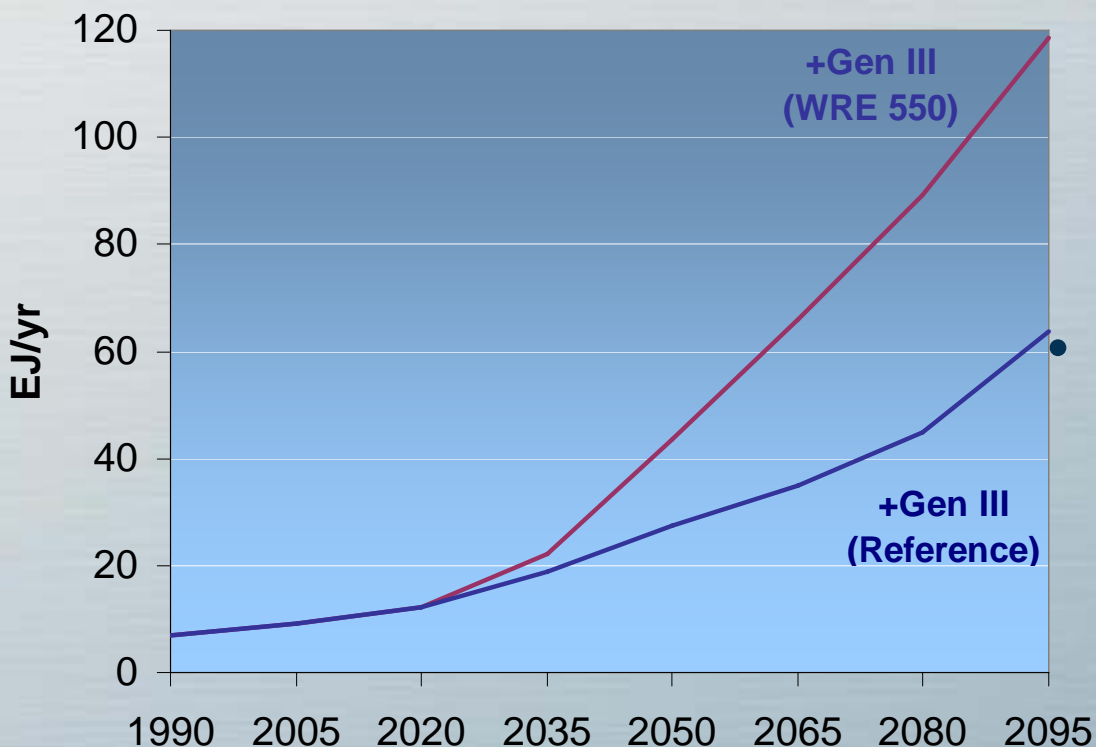


- The time scale of emissions mitigation is a century or more.
- Energy technology will be needed to help control emissions in the NEAR-, MID-, and Long-term to address climate change.
- Investments in basic scientific research in the first half of the 21st century can be transformed into energy technologies that can become a major part of the global energy system in the second half of the century.

Nuclear energy

Climate policy accelerates the expansion of the market for nuclear power...

Global Nuclear Electricity Generation

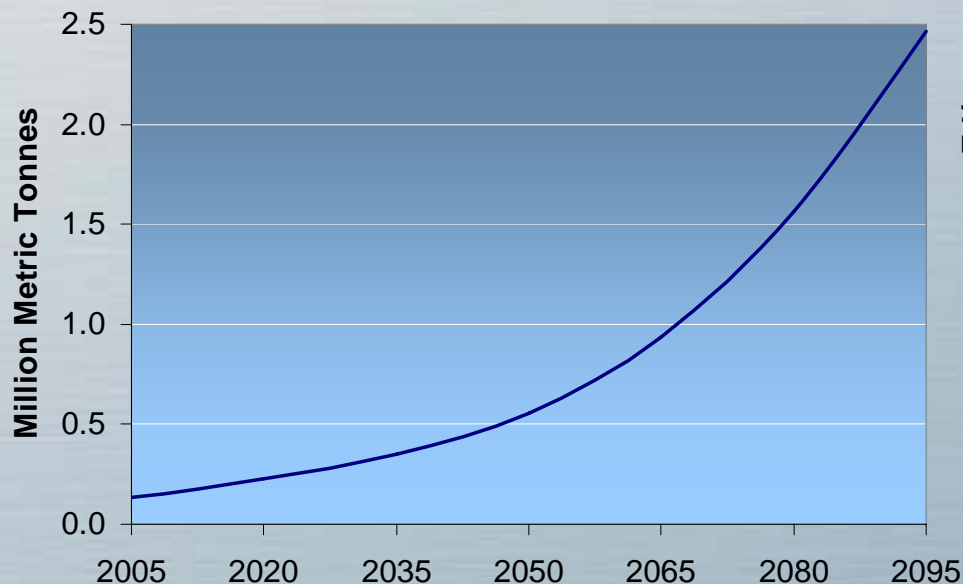


- Regardless of whether there is a global climate policy that seeks to stabilize atmospheric concentrations of greenhouse gases, nuclear energy is already an important energy supplier and is expected to continue to expand throughout this century.
- The market for nuclear power to generate hydrogen for the transportation sector is a small portion of the market for electricity.

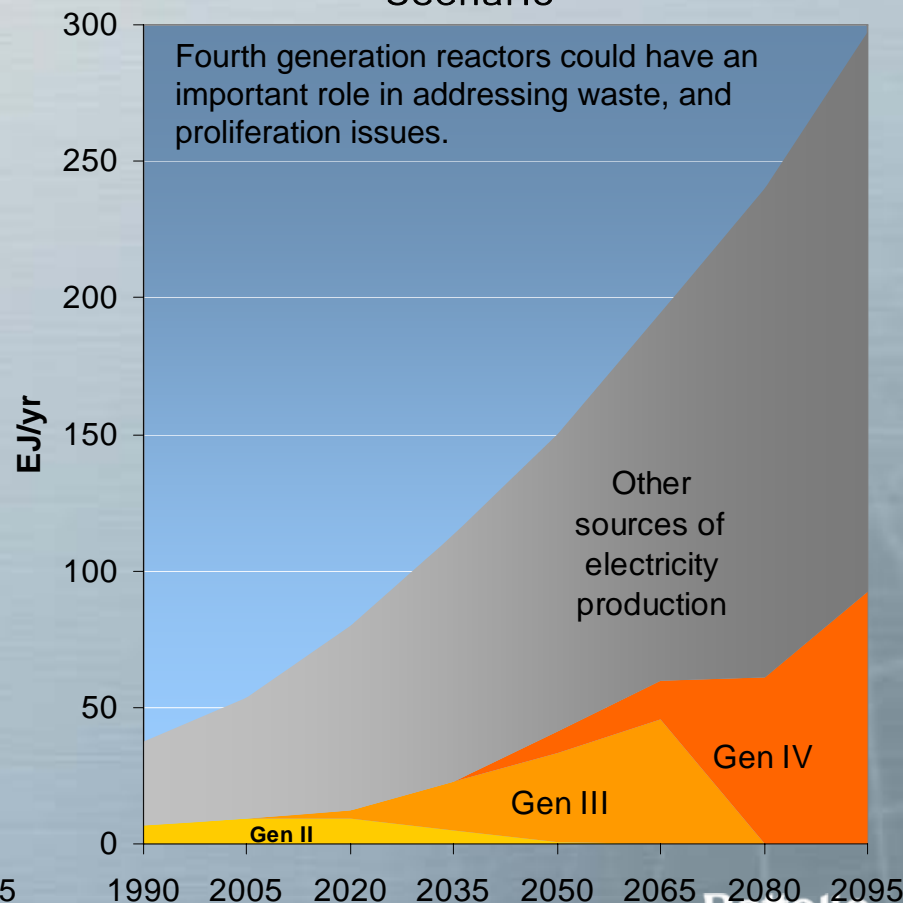
Issues that, while difficult to quantitatively model, might impact the projected growth of nuclear power in the 21st century.

- Public policies designed to address proliferation concerns
- Nuclear waste

Global Nuclear Spent Fuel Waste Third Generation Reactors Under a 550 ppm Stabilization Scenario



Nuclear Power Production by Technology 550 ppm Stabilization Scenario



Bioenergy and Land use

Biotechnology—One of the 6 Key Technologies that Could Deploy Dramatically in a Climate- Constrained World

- Biotechnology is itself a portfolio of technologies
 - Soil carbon
 - Sequestration via reforestation and afforestation
 - Growth of crops for their energy content
 - Potential advances from the biological revolution in science.
- Bioenergy crops are particularly interesting because they potentially offer a way to produce energy without producing any net CO₂ emissions.

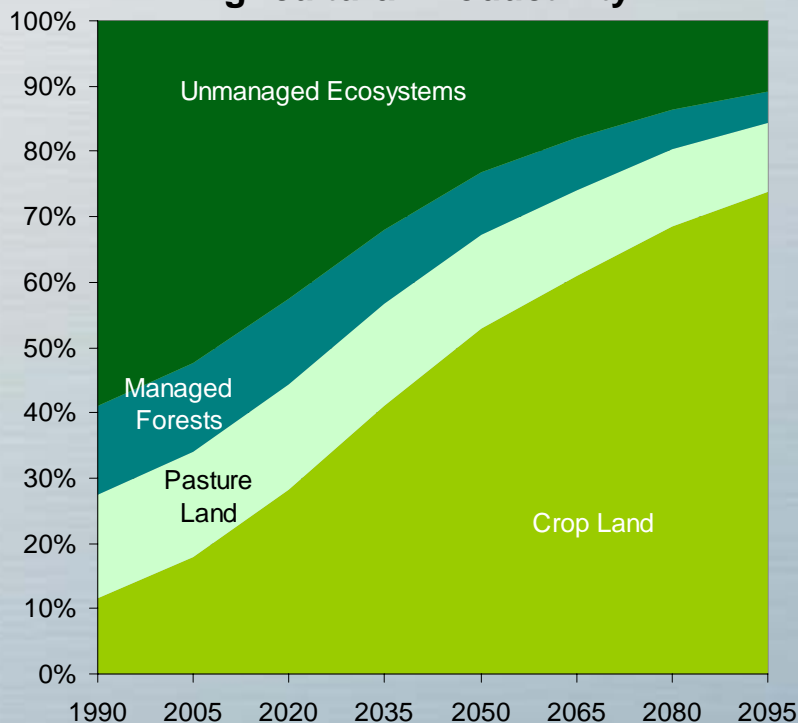
Some Insights from Our Research on Biotechnology

- In a climate-constrained world bioenergy crops could become the largest single crop grown by humans on the planet.
- The development of a bioenergy industry fueled by purpose-grown bioenergy crops depends on continued growth in non-biomass crop productivity as well as progress in bioenergy crop productivity.
- Technologies can work in combinations. Combining bioenergy with CO₂ capture and storage could provide a way to produce energy and produce **NEGATIVE** emissions of CO₂.

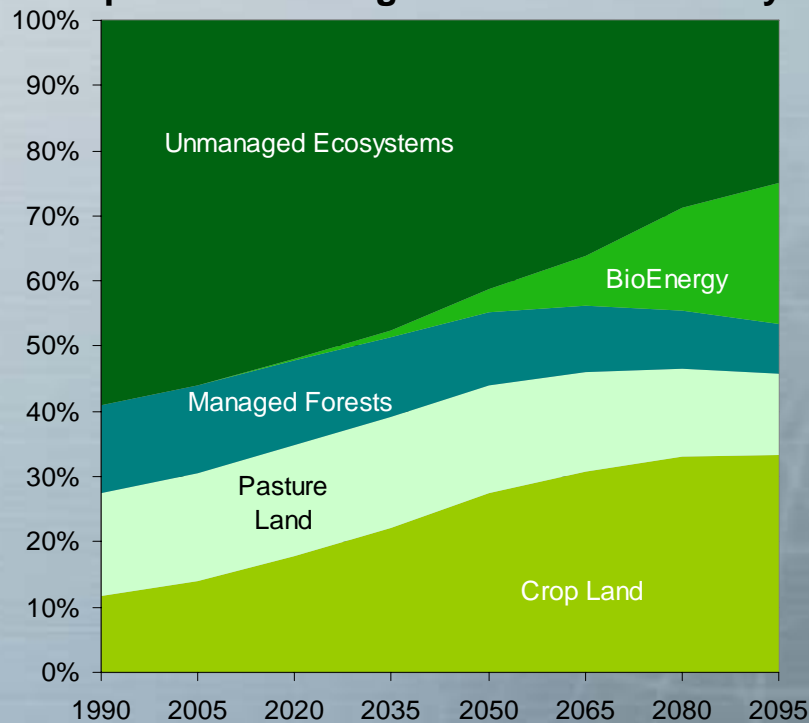
Technology Interplay— Bioenergy with Agricultural Productivity

The successful deployment of bioenergy in a climate-constrained world depends as much on the continued productivity advances for non-energy crops as for the energy crops—no one is making more land.

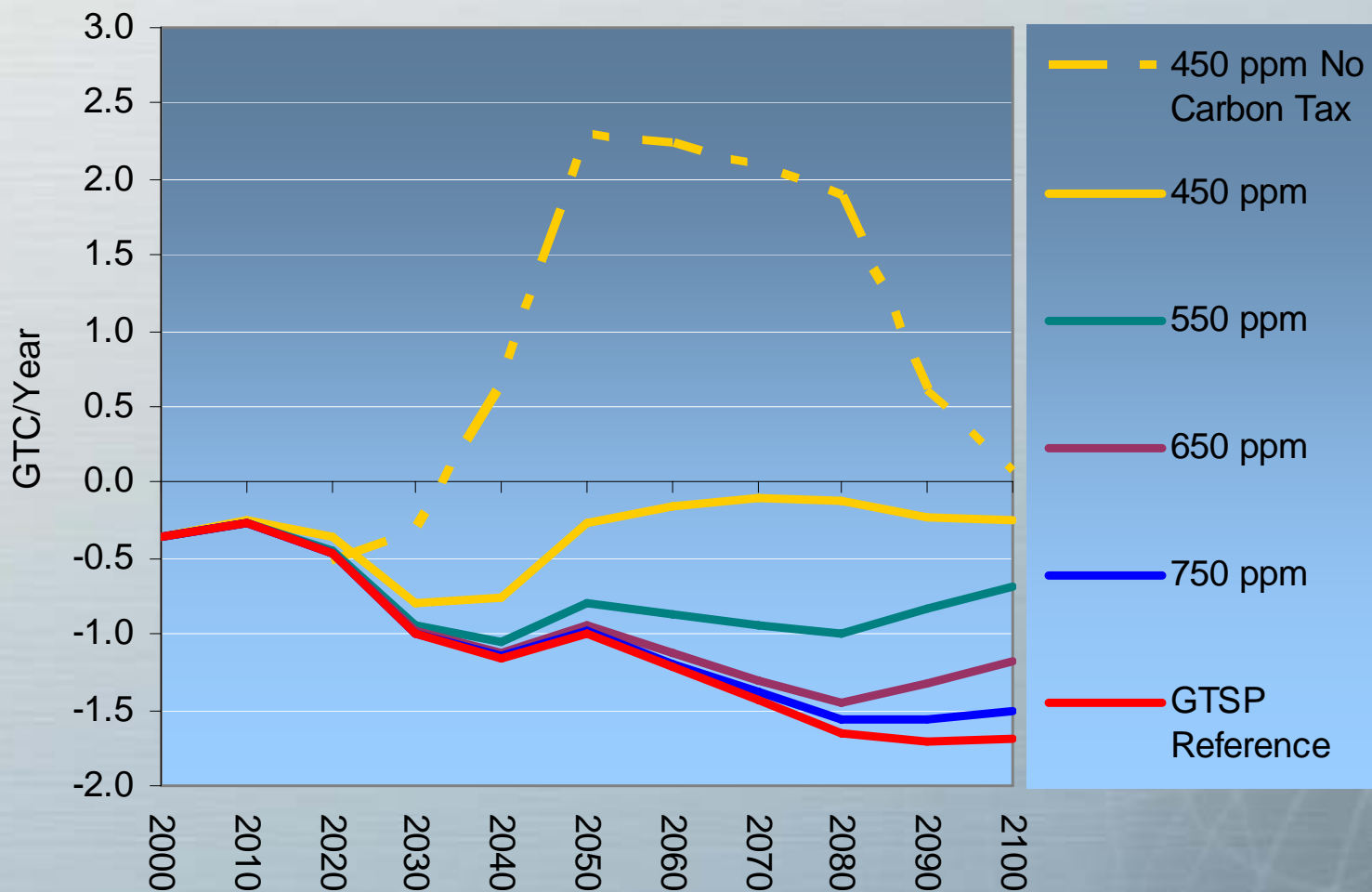
550 ppm Stabilization: No Improvement in Agricultural Productivity



550 ppm Stabilization: 0.5% per Year Improvement in Agricultural Productivity



To the atmosphere all carbon counts the same. Carbon cycle implications of valuing terrestrial carbon emissions

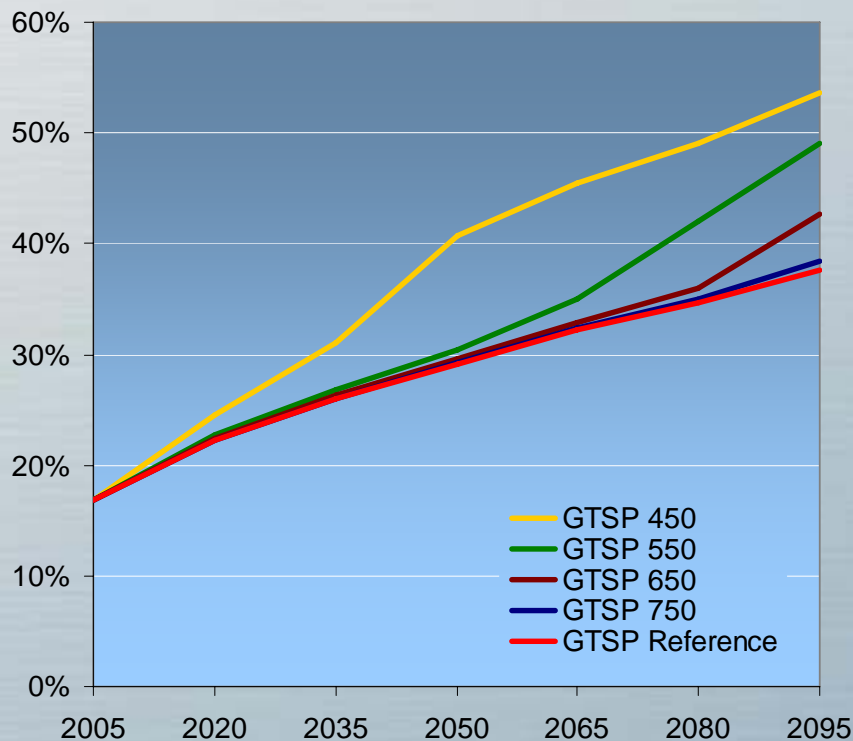


End use energy efficiency and fuel choice

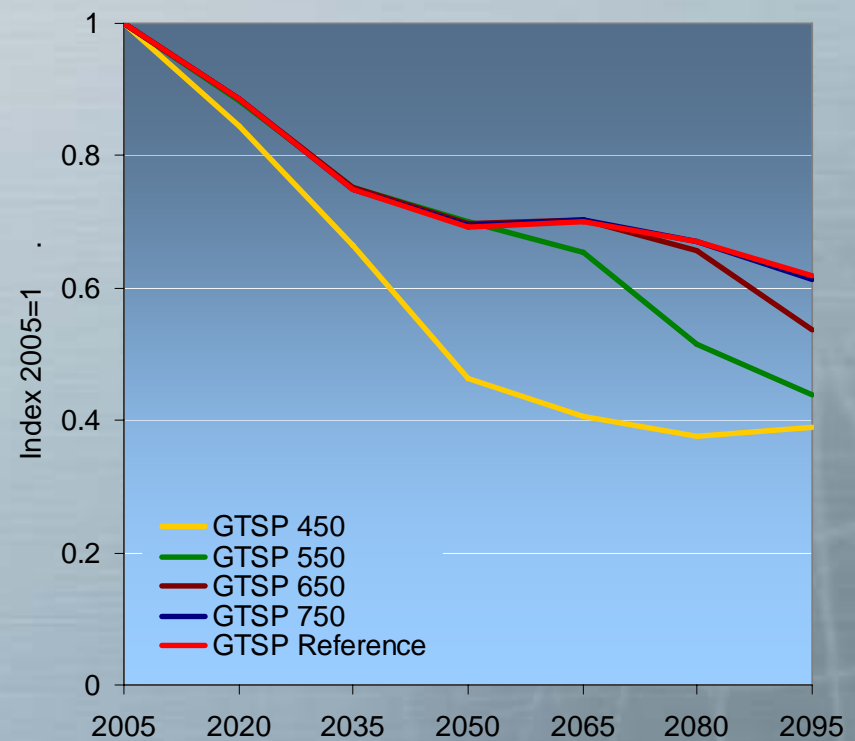
Electrification

- The world is electrifying.
- Emissions mitigation increases the relative role of electricity.
- Electricity prices fall relative to fossil fuel prices.

Electricity as a Percentage of Total Final Energy



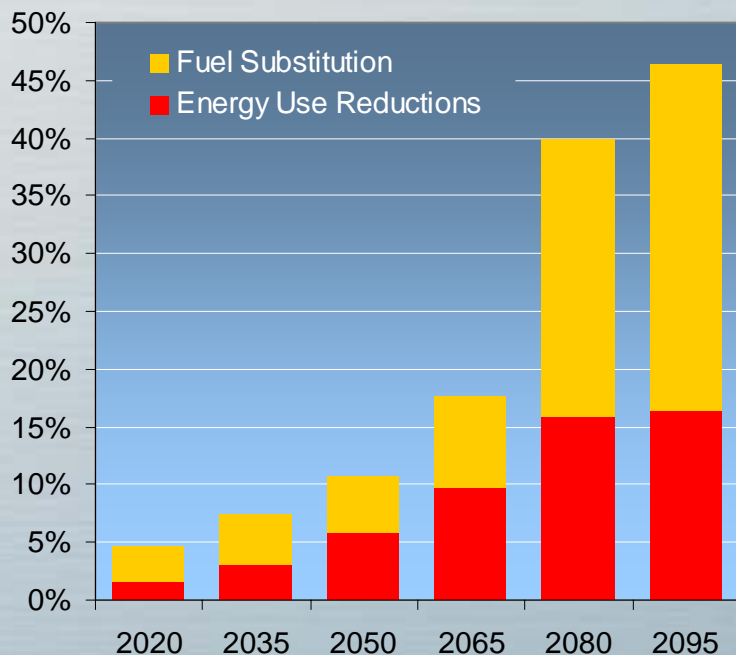
Average Electricity Price Relative to Oil Price



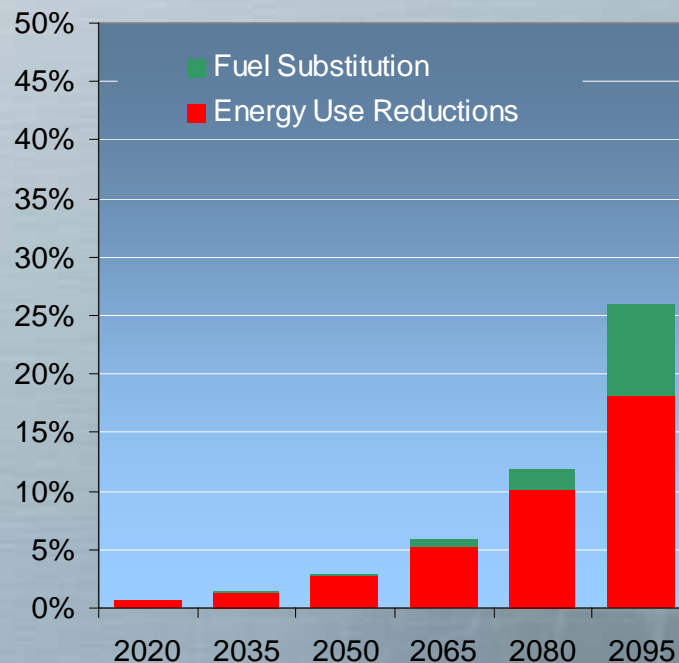
End-use Energy Technologies

- Three sectors
 - Buildings
 - Industry
 - Transportation
- Emissions reductions come from two sources
 - Energy efficiency improvements
 - Fuel substitution

Buildings 550 ppm



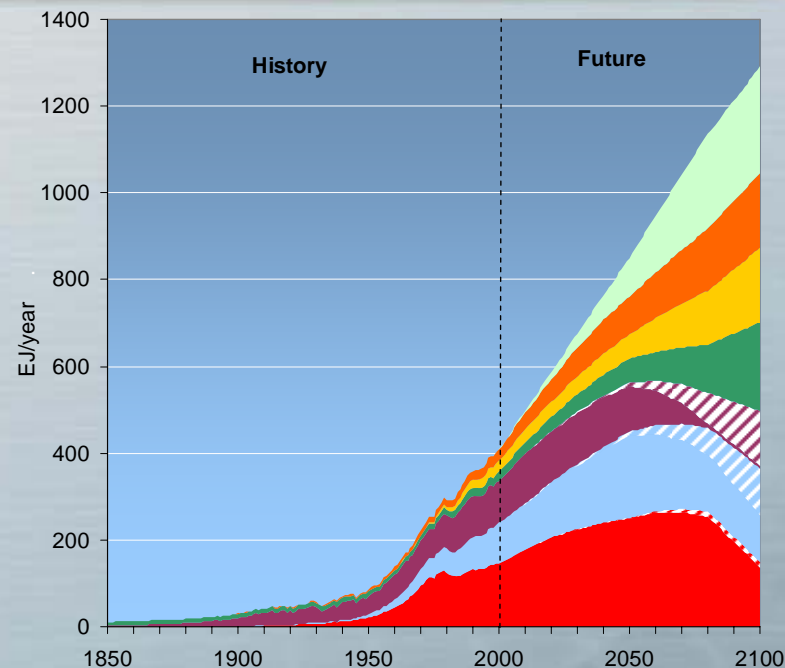
Transportation 550 ppm



Stabilization of CO₂ concentrations means fundamental change to the global energy system

... but the character of the global energy system will depend on technology developments:

- CO₂ capture and storage (CCS) plays a potentially large role assuming that the institutions make adequate provision for its use.
- Biotechnology has dramatic potential, but important land-use implications.
- Hydrogen could be a major new energy carrier, but requires important technology advances in fuel cells and storage.
- Nuclear energy could deploy extensively throughout the world but public acceptance, institutional constraints, waste, safety and proliferation issues remain.



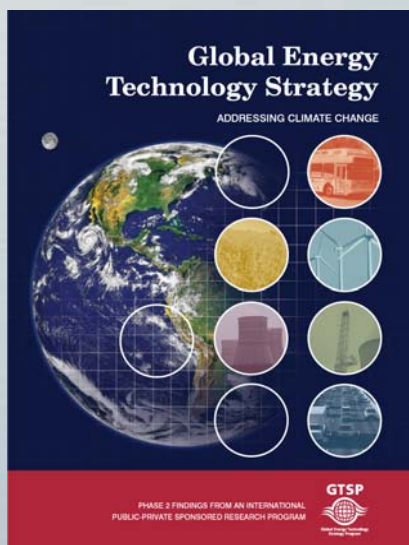
- Wind & solar could accelerate their expansion particularly if energy storage improves.
- End-use energy technologies that improve efficiency and/or use energy carriers with low emissions, e.g. electricity deploy more extensively.

Technology in the Near, Mid, and Long Term

- The challenge of scale grows exponentially over the century
- The role of technology is to help manage the cost of stabilizing greenhouse gas concentrations.
 - Emissions mitigation starts with the existing suite of technologies.
 - Improving the existing suite of technologies will help to lower the cost of stabilization.
 - In the long term that suite of improving technology options can be augmented by new technology options, some of which do not yet have names. Those technologies will emerge out of near-term investments in basic and applied science across a broad range of research domains.

The GTSP Report

Copies of the Report are Available upon request



And on the Web

<http://www.pnl.gov/gtsp>

or

<http://gtsp.battelle.org>